Model Tests for Strip Foundation on Clay Reinforced with Geotextile Layers

JONI P. SAKTI AND BRAJA M. DAS

The ultimate bearing capacity of a model strip foundation resting on a saturated soft clay internally reinforced with geotextile layers has been investigated in the laboratory. The geotextile used for the study was heat-bonded nonwoven polypropylene. On the basis of the present test results, geotextile layers placed under a foundation within a depth equal to the width of the foundation have some influence on the increase of the short-term ultimate bearing capacity. For maximum efficiency, the first layer of geotextile should be placed at a depth of about 0.4 times the width of the foundation. The minimum length of the reinforcing geotextile layers for maximum efficiency appears to be about four times the width of the foundation.

Shallow foundations constructed over soft saturated clay layers have low ultimate bearing capacity. They also undergo large elastic settlements. One of the possibilities for increasing the short-term bearing capacity of a shallow foundation is by reinforcing the clay under the foundation by means of geotextile layers (Figure 1). A review of the existing literature shows that relatively little is known at this time about how to quantify the parameters involved in estimating the increase of immediate load bearing capacity of shallow foundations resting on saturated clayey soil ($\phi = 0$ condition) internally reinforced with geotextile layers. The purpose of this paper is to present the experimental results of some small-scale laboratory bearing capacity tests on model strip foundations resting on clay reinforced with geotextiles.

LABORATORY MODEL TEST PROCEDURES

The laboratory bearing capacity tests were conducted in a clayey soil that had 100 percent passing No. 10 U.S. sieve (2.0 mm opening), 86 percent passing No. 40 U.S. sieve (0.425 mm opening), and 62 percent passing No. 200 U.S. sieve (0.075 mm opening). The liquid and plastic limits of the soil were 35 and 24 percent, respectively. A large amount of soil was brought to the laboratory and pulverized well. The soil was then mixed with a desired amount of water and transferred to several plastic bags that were sealed and stored in a moist curing room for about 1 week before use. The average moisture content during the actual model tests was 25.1 percent.

J. P. Sakti, Department of Civil Engineering, Ohio State University, Columbus, Ohio 43210. B. M. Das, Department of Civil Engineering, University of Texas at El Paso, El Paso, Tex. 79968.

The model foundation used for the laboratory tests was 76.2 mm wide, 228.6 mm long, and 9.5 mm thick. It was cut from an aluminum plate. The model test box was 652 mm long, 76.2 mm wide, and 610 mm high. The sides of the box were heavily braced to avoid lateral yielding during soil compaction and during testing. The inside of the test box was polished to avoid friction between edges of the model foundation and the box. The geotextile used in the laboratory tests was Mirafi 140N, a heat-bonded nonwoven type with polypropylene geotextile. Typical average properties of the geotextile as given by the supplier were as follows: grab tensile strength = 534 N (ASTM D-1682-64); grab tensile elongation = 55 percent; burst strength = 1,440 kN/m^2 (ASTM D-3786-80).

To conduct the model tests in the laboratory, the moist soil was compacted in 25- to 51-mm-thick layers in the test box up to the desired height. Geotextile layers of various lengths L with widths equal to the width of the test box were laid in the clay soil during the compaction. After completion of the compaction process, the model footing was centrally placed at the top of the clay. Load to the foundation was applied by means of a hydraulic jack. The load on the model footing was measured with a proving ring, and the corresponding deflection was obtained from a dial gauge. Figure 2 shows a schematic diagram of the experimental setup.

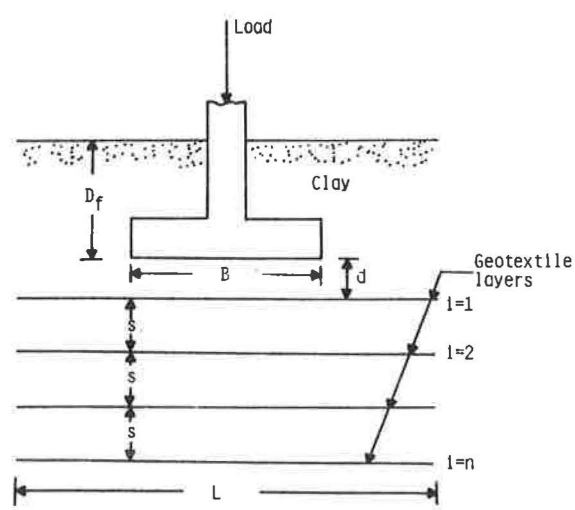

FIGURE 1 Shallow foundation on clay internally reinforced with geotextile layers.

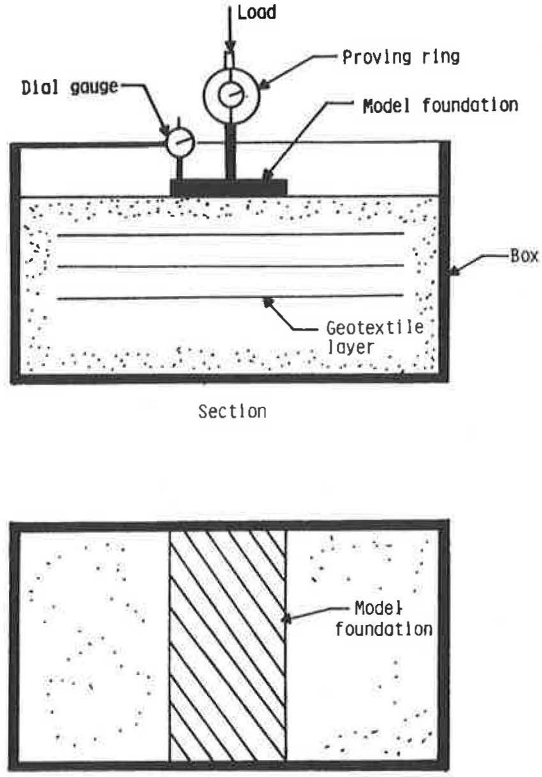

FIGURE 2 Schematic diagram of laboratory test arrangement.

SEQUENCE OF MODEL TESTS AND PARAMETERS STUDIED

All model tests conducted under this program were of the plane-strain type. Table 1 presents the sequence of experiments and other details of the tests. All tests except Test 2 were conducted with the moist clay medium, which had an average undrained shear strength of 22.5 kN/m^2 at an average moisture content of 25.1 percent and degree of saturation of about 96 percent. Test 2 was conducted on the compacted clay at a moisture content of 21.8 percent with an average undrained shear strength of 29 kN/m^2. The average degree of saturation of the clay for this test was 94.8 percent.

The model tests were conducted to evaluate the following: (a) the increase in the ultimate bearing capacity of foundations due to geotextile reinforcement and the optimum placement of geotextile layers for obtaining the maximum efficiency; (b) the settlement of foundations at ultimate load with and without geotextile reinforcement; and (c) the optimum length of geotextile layers to mobilize the ultimate bearing capacity.

The laboratory test results and the evaluation of the above factors are given in the following section.

EXPERIMENTAL RESULTS

Bearing Capacity of Reinforced Clay

Figure 3 shows the average plot of load versus displacement for the model foundation as observed in the laboratory for Tests 1 and 2, which were conducted in compacted clay without geotextile reinforcements. As seen from Figure 3, the nature of failure is of local shear type. The ultimate loads for the tests were determined in a manner suggested by Vesic *(1)*. The ultimate load was defined as the point at which the load-displacement plot became practically linear. For surface foundations ($D_f = 0$) in clay for the $\phi = 0$ condition,

$$Q_u = c_u N_c A \tag{1}$$

where

Q_u = ultimate load,
N_c = bearing capacity factor,
A = area of the model foundation, and
c_u = undrained shear strength of clay.

So

$$N_c = \frac{Q_u}{AC_u} \tag{2}$$

For Tests 1 and 2, the ultimate loads Q_u were 2,180 and 2,758 N, respectively. By using the proper values of c_u and A, the values of N_c were determined to be 5.57 and 5.46, respectively. These values are in the general range predicted by Prandtl *(2)* and Terzaghi *(3)*. The ultimate load occurred at a settlement of 16 to 18 percent of the width of the foundation.

Bearing Capacity of Clay with Geotextile Reinforcement

Model Tests 3 through 26 were conducted on clay with geotextile reinforcements that had length L equal to 10 times the footing width B (Table 1). Figure 4 shows typical plots of load versus displacement for Tests 8–12. For comparison purposes, the average relationship between load and displacement for Test 1 (on clay without reinforcement) has also been plotted in Figure 4. In general, for a given settlement, the load-carrying capacity of the model foundation increased when the geotextile reinforcement in the clay was introduced. The ultimate loads for all tests (Tests 1 and 3–26) as determined in the manner suggested by Vesic *(1)* have been compiled and are shown in Figure 5 for various combinations of d/B, s/B, and n (definitions of d, s, and n are given in Table 1). For given values of d/B and s/B, the magnitude of Q_u increased with n up to a maximum value $Q_{u(\max)}$ and remained constant thereafter. Binquet and Lee *(4)* have introduced the concept of bearing capacity ratio *(BCR)*, defined as

$$BCR = \frac{Q_{u(\text{reinforced})}}{Q_{u(\text{unreinforced})}} \tag{3}$$

In Figure 5, the scale of *BCR* is shown on the ordinate on the right hand side. The variation of the maximum bearing capacity ratio, $BCR_{(\max)}$, for different values of d/B and s/B as determined from Figure 5 is shown in Figure 6. The following

TABLE 1 SEQUENCE OF LABORATORY TESTS

Test No.	Depth of model foundation, D_f	d/B	Number of geotextile layers, n	s/B	L/B	Remarks
1	0	--	0	--	--	c_u=22.5 kN/m^2--test on clay alone γ=20.13 kN/m^3
2	0	--	0	--	--	c_u=29 kN/m^2--test on clay alone γ=20.76 kN/m^3
3	0	0.25	1	0.33	10	c_u=22.5 kN/m^2
4	0	0.25	2	0.33	10	
5	0	0.25	3	0.33	10	γ=20.13 kN/m^3
6	0	0.25	4	0.33	10	
7	0	0.25	5	0.33	10	
8	0	0.33	1	0.33	10	c_u=22.5 kN/m^2
9	0	0.33	2	0.33	10	
10	0	0.33	3	0.33	10	γ=20.13 kN/m^3
11	0	0.33	4	0.33	10	
12	0	0.33	5	0.33	10	
13	0	0.67	1	0.33	10	c_u=22.5 kN/m^2
14	0	0.67	2	0.33	10	
15	0	0.67	3	0.33	10	γ=20.13 kN/m^3
16	0	0.67	4	0.33	10	
17	0	1.00	1	0.33	10	c_u=22.5 kN/m^2
18	0	1.00	2	0.33	10	
19	0	1.00	3	0.33	10	γ=20.13 kN/m^3
20	0	0.67	1	0.67	10	c_u=22.5 kN/m^2
21	0	0.67	2	0.67	10	
22	0	0.67	3	0.67	10	γ=20.13 kN/m^3
23	0	0.67	4	0.67	10	
24	0	1.00	1	1.00	10	c_u=22.5 kN/m^2
25	0	1.00	2	1.00	10	
26	0	1.00	3	1.00	10	γ=20.13 kN/m^3
27	0	0.33	4	0.33	2	c_u=22.5 kN/m^2
28	0	0.33	4	0.33	3	
29	0	0.33	4	0.33	4	γ=20.13 kN/m^3
30	0	0.33	4	0.33	5	
31	0	0.33	4	0.33	6	
32	0	0.33	4	0.33	8	

B=foundation width
L=length of geotextile layer (Fig. 1)
d=distance between the bottom of the foundation and the first geotextile layer (Fig. 1)
s=spacing between geotextile layers (Fig. 1)
γ=moist unit weight
c_u=undrained shear strength

Note: Average moisture content-25.1%; average degree of saturation=96%

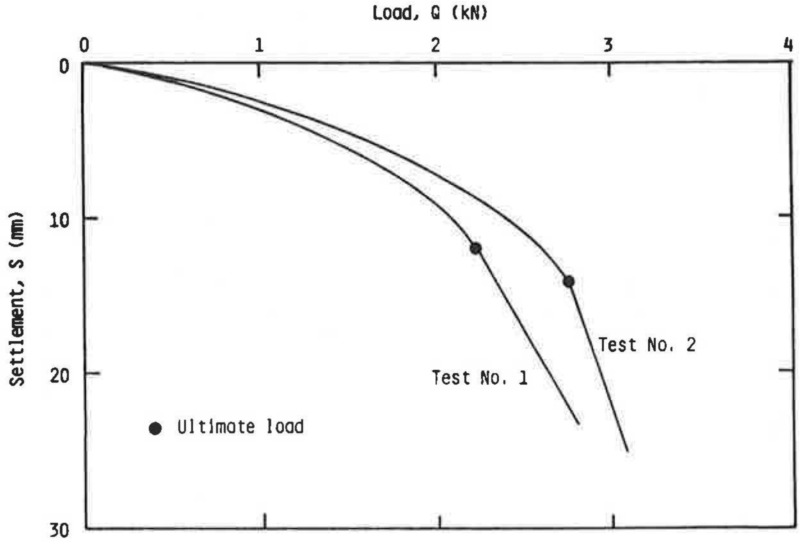

FIGURE 3 Average load-displacement diagram for Tests No. 1 and 2.

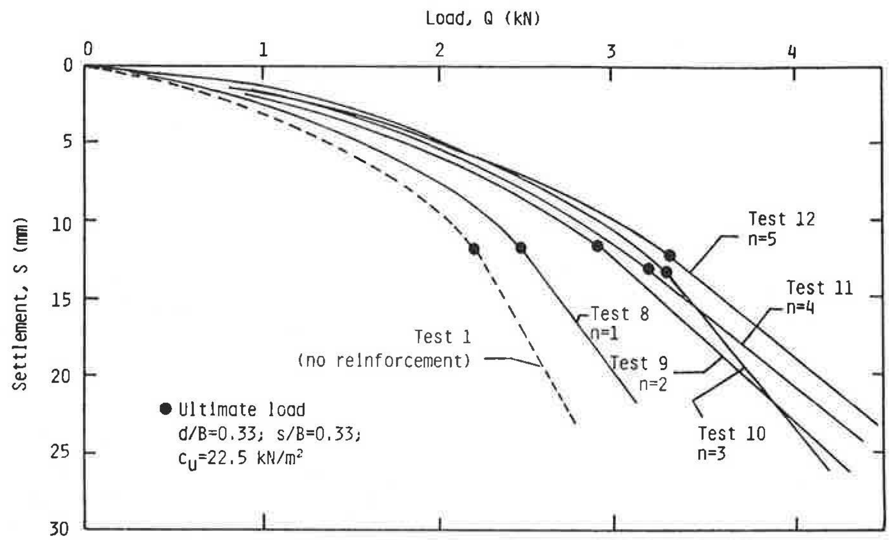

FIGURE 4 Typical load-displacement diagrams for foundation on clay internally reinforced with geotextile.

general observations can be made from the data shown in Figures 5 and 6:

1. For a given number of geotextile reinforcement layers, the maximum value of $BCR_{(max)}$ is obtained when d/B is about 0.35 to 0.4.
2. For a given number n of geotextile reinforcement layers and a given s/B, the magnitude of $BCR_{(max)}$ decreases with increasing d/B. However, when $d/B = 1.0$, $BCR_{(max)}$ is also approximately equal to 1.0.
3. The preceding statement implies that geotextile reinforcements placed below a depth equal to B do not create an increase in the ultimate bearing capacity. Thus

$$D_{eff} \cong B = d + s(n_{cr} - 1) \tag{4}$$

where

D_{eff} = effective depth (i.e., the depth below the foundation beyond which the placement of geotextile reinforcement does not have any effect on bearing capacity) and

n_{cr} = critical number of layers of geotextiles beyond which any increase does not contribute to the bearing capacity increase.

So

$$n_{cr} = \frac{B - d}{s} + 1 \tag{5}$$

However, for most effective design, $d \cong 0.4B$.

$$n_{cr} = \frac{0.6B}{s} + 1 \tag{6}$$

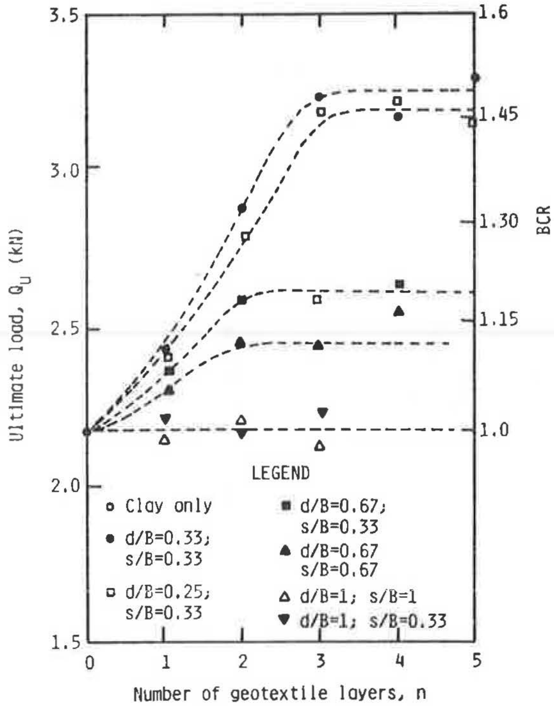

FIGURE 5 Variation of Q_u and BCR with s/B, d/B, and n.

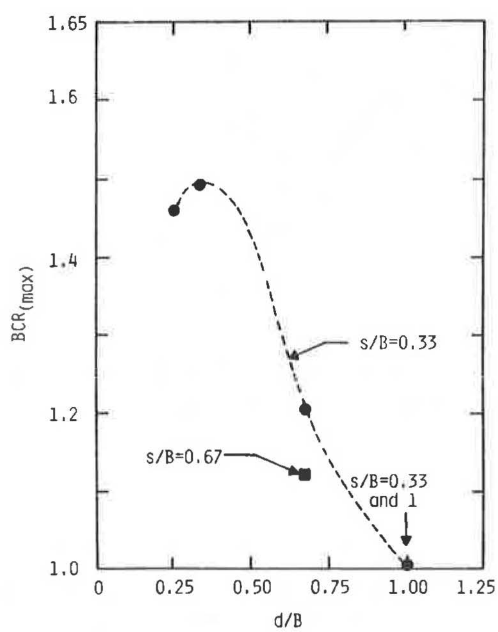

FIGURE 6 Variation of BCR_{max}.

Settlement at Ultimate Load

For all the tests conducted under this study, the settlements at ultimate load (with or without geotextile reinforcement) were in a range of 14 to 18 percent, with an average of 16 percent of the foundation width. The load versus displacement relationships shown in Figure 4 are typical for all tests conducted under this program. However, for all tests with geotextile reinforcements, the slope of the load-displacement diagrams (i.e., $\Delta S/\Delta Q$) was somewhat smaller than that observed for tests on unreinforced clay, or

$$\left(\frac{\Delta S}{\Delta Q}\right)_{\text{reinforced}} < \left(\frac{\Delta S}{\Delta Q}\right)_{\text{unreinforced}} \tag{7}$$

Length of Geotextile Reinforcement Layers

Tests 28–32 (Table 1) were conducted to determine the optimum length L of geotextile layers to be used as reinforcements to mobilize the maximum bearing capacity ratio. The

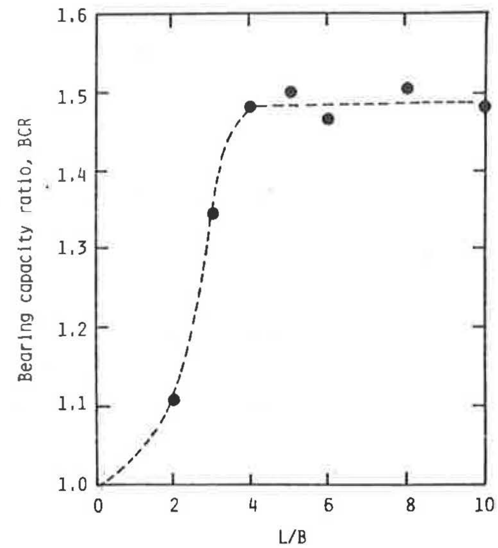

FIGURE 7 Variation of BCR with L/B (Tests No. 11, 27–32; n = 4, s/B = 0.33, and d/B = 0.33).

tests were conducted with similar values of c_u, d/B, and s/B. A nondimensional relationship between BCR and L/B for these tests is shown in Figure 7. The magnitude of BCR increases with L/B and reaches a maximum value at about L/B between 3 and 4. For $L/B > 4$, the magnitude of BCR remains practically constant.

CONCLUSIONS

The results of a number of laboratory model tests for evaluation of the ultimate bearing capacity of a strip surface foundation resting on a nearly saturated clay layer reinforced with several layers of geotextiles have been presented. On the basis of the present study, the following conclusions can be drawn:

1. Inclusion of geotextile layers in saturated or nearly saturated clays increases the ultimate bearing capacity of foundations under undrained conditions.
2. The most beneficial effect of geotextile reinforcement on the bearing capacity is realized when the first layer is placed at a depth (d/B) of about 0.35 to 0.4 below the bottom of the foundation.
3. Reinforcements placed below a depth B measured from the bottom of the foundation do not have any influence on the ultimate bearing capacity of a foundation.

4. The most effective number of geotextile reinforcement layers (for $d < B$) can be obtained from Equation 6.

5. Geotextile reinforcements do not have much influence on the foundation settlement at ultimate load. For the present tests, the ultimate load occurred at a settlement of about $0.16B$ to $0.18B$, which is large.

6. The most effective length of geotextile layer obtained from these tests is about $4B$. However, this may change depending on the type of geotextile used. More research needs to be done in this area.

7. The results presented in this paper are based entirely on laboratory model tests. The applicability of the findings in this study to the field conditions needs to be confirmed by large-scale tests. Hence, caution must be exercised in using the present results for field design.

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